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A fine-grain approach for evaluating the quality of context

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Abstract—Context-aware applications are becoming commonplace in everyday life thanks to recent advances in mobile devices, sensor capabilities and wireless communication networks. However, making the manipulation of context information efficient is still an important issue. Taking into account the quality of context data becomes a corner stone of an efficient context management. In this paper, we argue for a fine-grain QoC reasoning. We build on existing application examples and implement one of them with the COSMOS framework. Our approach allows for a better control of the behavior of pervasive applications.

Keywords-Context management, Quality of context, QoC reasoning

I. INTRODUCTION

Context-aware applications are becoming commonplace in everyday life thanks to the recent advances in mobile devices, sensor capabilities and wireless communication networks. However, making the manipulation of context information efficient is still an important issue. Context data prove to be inherently uncertain due to the imperfection of physical sensors and of the real world itself [3]. Knowing the quality of context helps to take appropriate decisions and allows to identify uncertain contexts saving processing time for deriving a pertinent description of the observed phenomenon. Taking into account the quality of context data thus becomes a corner stone of an efficient context management solution and has given rise to a number of research works over the past decade. The importance of the quality of context as such for context-aware computing has first been raised by [6]. This concept has then been refined with a notion of worth: quality of context is any inherent information that describes context information and can be used to determine the worth of the information for a specific application [16]. Furthermore, [4] has identified specific quality criteria for the information originated from sensors, evaluating the cost for collecting the sensed data and focusing on establishing the timeliness and the reliability of the detection of events of interest.

We have shown in [1] how we manage QoC dynamically with the COSMOS framework [7]. Context data coming from distributed sources can be checked, filtered and compared thanks to their QoC which is computed at any layer of the context management architecture. Different QoC

requirements are defined for different applications. In this paper, we propose to refine the way QoC is managed to enable a precise evaluation of quality metadata. After the identification of the various quality parameters relevant to the application, we determine the importance weight of each of them along an iterative process. The way these importance weights are computed is specific to each application, or even, it can change over time for the same application when the usage scenario changes.

This paper is organised as follows. Section II details our proposition for a fine-grain QoC reasoning. In section III, we build on existing application examples to show how the proposition works and explain how we implemented one of them with the COSMOS framework. In section IV, we discuss some related works on QoC management. Section V concludes this paper and draws up plans for future work.

II. QOC REASONING

A. Introduction

Context information originates from a variety of sources that differ in the quality of the information they produce and that can be error prone. A pervasive application receives information from multiple sensors through a context manager. These sensors may collect the same type of information from the environment. The context manager must then obtain the most relevant information for the application. Taking into account the quality of context (QOC) is a way to choose the best source according to different quality parameters such as:

- **Freshness** (or up-to-dateness) Derived from the age of the context attribute value, it indicates the degree of rationalism of using a context object at a given time [18]. It represents the fact that a sensor reading has an expiry time, beyond which the reading is no longer valid [3].
- **Accuracy** corresponds to the difference between the value of the context attribute and the aspect of reality it represents [13].
- **Trustworthiness** represents the probability estimated by the receiver of a context attribute value that the context source provided the correct value [13].
- **Completeness** This quality measure indicates the quantity of information that is provided by a context object.

In [15] completeness has been computed as the ratio of the number of attributes available to the total number of attributes. [18] have enhanced this concept by using weights for the different attributes.

- **Reliability** In [27], the reliability is presented as a measure of self-confidence.

B. Proposition

Consider two sensors $S1$ and $S2$ sending the same type of information. How can we compare the quality of the information provided by both sensors? For an adequate comparison of the context information, we propose to construct an overall quality indicator that considers the importance of each quality parameter.

1) Choice of relative weights for QoC parameters:

The construction of the weights of the considered quality parameters is done by comparing the importance of these parameters in pairs in order to specify a relative weight. This weight corresponds to the estimation of the parameter's priority over another quality parameter. We use the \prec operator to indicate the relative order of the different quality parameters and read it *more important*. The sum of all the relative weights results in an absolute weight.

To choose a relative weight, we propose in table I a scale to compare the importance of a QoC parameter over another one. This scale is inspired by the *Richter magnitude scale* [22] in specifying different degrees of importance. After a comparison of the different quality parameters with one another from the point of view of the application and referring to table I, a corresponding value is added to the *most important* parameter's relative weight. For an emergency application, for example, context information freshness can be considered as highly important comparing to trustworthiness. If the initial weight of the freshness is $w_F = 1$ and of the trustworthiness is $w_T = 1$, the relative weights will be (after this comparison) $w_F = 2$ and $w_T = 1$.

Relation	Value added to relative weight
equivalent	+0
barely	+0.1
just a little	+0.2
somewhat	+0.5
highly	+1
much	+5
tremendously	+10

Table I
QOC PARAMETERS' WEIGHTING SCALE

The next paragraph shows a complete example of how to build relative weights.

2) *Example of the use of the QoC scale:* We consider three QoC parameters : Freshness (F), Accuracy (A) and Trustworthiness (T).

We consider that we begin with equal initial weights for all parameters : $w_F = 1$, $w_T = 1$ and $w_A = 1$. A domain expert would then compare the importance of each QoC parameters for the application (or just some part of the application) as follows:

- Freshness barely \prec Accuracy (read: *Freshness is barely more important than Accuracy*)
- Freshness highly \prec Trustworthiness
- Accuracy somewhat \prec Trustworthiness

Table II summarizes the process for building the relative weight step by step for each QoC parameter from the expert decision and referring to table I to obtain absolute weights.

	Freshness (F)	Accuracy (A)	Trustworthiness (T)
initial weight	1	1	1
relative F/A	1.1	1	1
relative F/T	2.1	1	1
relative A/T	2.1	1.5	1
absolute weight	2.1	1.5	1

Table II
CONSTRUCTING QOC PARAMETERS' WEIGHTS

3) *Overall QoC computation:* Let $q_{i,j}$ be the i^{th} quality parameter for the j^{th} context information, with $1 \leq i \leq n$ and $1 \leq j \leq p$. We compute the overall QoC of the j^{th} context information as follows :

$$QoC_j = \frac{\sum_{i=1}^n w_i \times q_{i,j}}{\sum_{i=1}^n w_i} \quad (1)$$

As an example, let $S1$ and $S2$ be two sensors sending periodically the temperature of a room. Each temperature measure is provided with the value of the two QoC parameters that we consider: F (1^{st} quality parameter) and T (2^{nd} quality parameter).

Computation of the freshness and trustworthiness: $S1$ has a period of $5min$ and 80% of trustworthiness ($q_{2,1} = 0.8$). $S2$ has a period of $9min$ and 95% of trustworthiness ($q_{2,2} = 0.95$). The maximum lifetime of a temperature measure is considered to be $30min$, meaning that a temperature measure is no longer considered as valid after $30min$ and will not be used. We can compute the freshness of the temperature information sent by each sensor as follows :

$$\mathcal{F}(\mathcal{O}) = 1 - \frac{Age(\mathcal{O})}{Lifetime(\mathcal{O})} \quad (2)$$

Consequently, the freshness of a temperature measure provided by each sensor is as follows:

$$q_{1,1} = 1 - 5/30 = 0.83$$

$$q_{1,2} = 1 - 9/30 = 0.7$$

Overall quality computation: If we compute the overall quality of context without introducing importance weighting, we obtain the following values :

- $QoC_1 = \frac{q_{1,1}+q_{2,1}}{2} = \frac{0.83+0.8}{2} = 0.815$
- $QoC_2 = \frac{q_{1,2}+q_{2,2}}{2} = \frac{0.7+0.95}{2} = 0.825$

In this case, it results that *S2* provides a better quality context than *S1*.

On the other hand, if we consider that freshness is somewhat more important than trustworthiness, implying that a weight of 1.5 is attributed to freshness, the overall quality is computed as follows :

- $QoC_1 = \frac{1.5 \times q_{1,1} + q_{2,1}}{2.5} = \frac{1.5 \times 0.83 + 0.8}{2.5} = 0.818$
- $QoC_2 = \frac{1.5 \times q_{1,2} + q_{2,2}}{2.5} = \frac{1.5 \times 0.7 + 0.95}{2.5} = 0.80$

Here, *S1* provides a better quality of context than *S2*.

III. APPLICATIONS

In this section, we consider two application examples coming from the research literature on pervasive applications and show how our approach allows to choose the best context source considering the relative importance of QoC parameters.

A. Family Stay in Touch service [2]

HyCoRe is designed as a generalized hierarchical hybrid reasoning engine that can capture the categorical characteristics of context. The authors aim to support both probabilistic and non-probabilistic reasoning techniques to enable knowledge sharing, context modularization and context aware application performance improvement.

1) *Scenario:* The HyCoRe scenario considers the father of a family being at a customer meeting and receiving several high priority communication texts from the *Stay in Touch* application. His child's school has left six messages each for him and his spouse at their respective work, mobile and home numbers. The texts indicate that it is early release today at 12:00. He then activates an application to handle this event behind the scene. Several appropriate persons able to pick up the child are then ranked by trust, proximity to the child's school and current availability. The persons are then automatically contacted and the Family service notifies the father when the child is in the custody of the designated person.

2) *Proposition:* We propose to extend the management of the QoC in this scenario by computing the freshness and the accuracy of the location, setting up the trustworthiness of the different persons and ranking situations according to their overall quality. Concerning the trustworthiness, the persons are considered as equally trustworthy, which is the case if the devices they use for location detection are similar. We could distinguish the trustworthiness of the two persons if we knew for instance that one uses a very recent device with a better positioning system. Moreover, we consider that

	<i>Context</i> ₁ Friend's location	<i>Context</i> ₂ Mother's location
1- Accuracy	$q_{1,1} = 0.5$ (WIFI)	$q_{1,2} = 0.7$ (GPRS)
2- Freshness	$q_{2,1} = 1 - 2/10 = 0.8$	$q_{2,2} = 1 - 5/10 = 0.5$

a)

	Case 1	Case 2
Weights	$w_1=1, w_2=2$	$w_1=2, w_2=1$
QoC	$QoC_1 = \frac{q_{1,1} + 2 \times q_{2,1}}{3}$ $= \frac{0.5 + 2 \times 0.8}{3}$ $= 0.7$ $QoC_2 = \frac{q_{1,2} + 2 \times q_{2,2}}{3}$ $= \frac{0.7 + 2 \times 0.5}{3}$ $= 0.57$	$QoC_1 = \frac{2 \times q_{1,1} + q_{2,1}}{3}$ $= \frac{2 \times 0.5 + 0.8}{3}$ $= 0.6$ $QoC_2 = \frac{2 \times q_{1,2} + q_{2,2}}{3}$ $= \frac{2 \times 0.7 + 0.5}{3}$ $= 0.63$
Context choice	<i>Context</i> ₁ is preferred The friend is notified	<i>Context</i> ₂ is preferred The mother is notified

b)

Table III
CONTEXT CHOICE FOR HYCoRE SCENARIO

GPRS has a better accuracy than WIFI as reported in [25]. We thus manipulate two QoC parameters, the freshness and the accuracy.

We assign a weight to each QoC parameter in order to compare context sources. The person to be contacted is then determined by the following reasoning. A family's friend with a WIFI device was near the child's school 2min ago. The mother with a GPRS device was near the child's school 5min ago. We consider that the lifetime of a location context is 10 min. This means for instance that the freshness of the mother's location is 0.5 (see Table III a)).

The context choice depends on the QoC parameters' weighting. *Context*₁ represents the friend's context and *Context*₂ the mother's one. Users' profiles and their locations are collected and manipulated by the COSMOS context management framework as shown in figure 1.

We show two different cases in Table III b). In Case 1, we assume that the accuracy is highly \prec than the freshness, so the freshness weight¹ is $w_F = 2$ and the accuracy weight is $w_A = 1$. This implies that *Context*₁ is better and the system will contact the friend. In Case 2, the freshness is considered as highly \prec than the accuracy and *Context*₂ is preferred.

3) *Implementation:* Our context manager relies on the COSMOS² (*C*ontext *e*ntitie*S* *c*o*M*positi*O*n and *S*haring) framework [7] which takes into account QoC information [1]. COSMOS reorganises the classical functionalities of a

¹In this example, the absolute weight is equivalent to the relative weight as we consider only two parameters

²<http://picoforge.int-evry.fr/projects/svn/cosmos/>

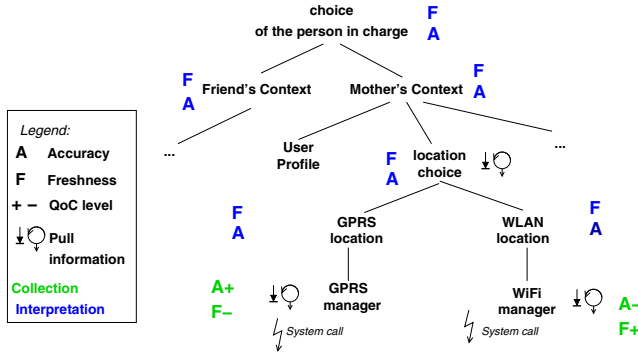


Figure 1. Part of the COSMOS tree for HyCoRe scenario

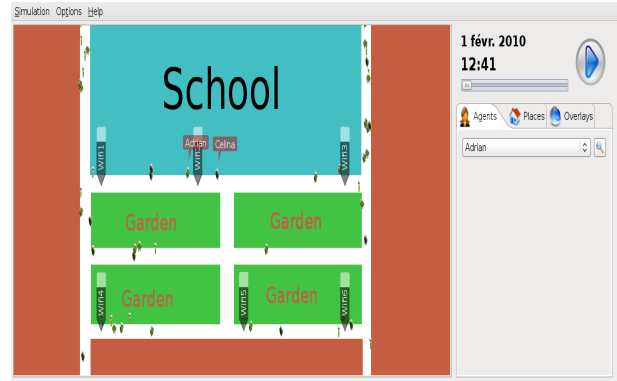


Figure 2. HyCoRe scenario in Siafu simulation

context manager to systematically introduce a 3-steps cycle of data collection, data interpretation, and situation identification. We decouple as much as possible these activities in order to obtain a non-blocking and efficient framework.

QoC is supported in COSMOS through the notion of QoC operator that can integrate various kinds of QoC parameter operators, dedicated to a particular QoC parameter. This approach is generic and our framework can easily be extended by adding new operators. To generate context information, we use the Siafu context simulator³.

```

1 <definition name="cosmos.qoc.scenario.contextnode.
  WlanLocation">
2 <component name="message-manager" />
3 <component name="activity-manager" />
4 <component name="wifimanager" />
5 <component name="gprsmanager" />
6 <attributes>
7 <attribute name="freshness_weight" value="2"/>
8 <attribute name="accuracy_weight" value="1"/>
9 </attributes>
10 </definition>

```

Listing 1. COSMOS QoC configuration for *Case₁*

The figure 1 represents the COSMOS tree that we have built to determine which person will be designated to be in charge of the kid to pick her up at the school. Listing 1 shows the COSMOS configuration to build Case 1 from table III. Figure 2 shows a simulation snapshot : the Celina Agent represents the mother and the Adrian agent represents a friend. In front of the school, there is a garden equipped with WIFI access points.

B. Epilepsy Safety System [13]

The CMS (Context Management Service) [13] is part of an infrastructure enforcing privacy and trust for the support of context-aware applications. It considers several QoC parameters such as accuracy, probability of correctness, trustworthiness and up-to-dateness. The Epilepsy Safety System (ESS) relies on this service in order to detect the

likely occurrence of a seizure and to contact nearby and trusted caregivers.

1) *Scenario*: In the ESS, the patient has a monitoring device that provides context information such as her location. Combined with her caregivers location and presence, this context information allows to deliver a personalised care for the patient. ESS uses information from context sources that wrap various positioning techniques (e.g., a GPS receiver, GSM cell IDs, and WiFi beacon spotting) and consider various levels of trustworthiness.

2) *Proposition*: In this example, the QoC management can be improved by adding QoC weighting. In addition to trustworthiness, other QoC parameters can be taken into account. Imagine that the ESS system detects two volunteer caregivers possessing the help application on their device but not yet registered implying that they have a poor trustworthiness value. However, it happens that they are the nearest ones to the patient. The first one provides some information about himself unlike the second one.

If the system takes into consideration the completeness of the context information as a second QoC parameter, QoC weighting can be introduced and impact the decision. If the *trustworthiness* weight is more important than the other QoC parameters, even if the two volunteers are the nearest ones, they will not be contacted. Now, if the *trustworthiness* weight is lessen letting these volunteers to be chosen, the first volunteer will be preferred as it shows a good *completeness*. Figure 3 illustrates a part of the COSMOS tree for this example. To take a suitable choice, the system gathers information from the profiles of the volunteers and verifies if the trustworthiness policy can accept such volunteers.

C. QoC management

Context information can be divided in several types. Based on the list presented in [2], we suggest in table IV a weighting importance for the QoC parameter in each context category. Context levels are categorized in *L* for low level context, *I* for intermediate context and *H* for high

³<http://siafusimulator.sourceforge.net>

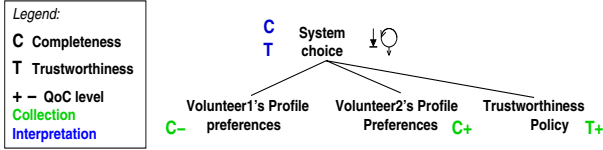


Figure 3. Part of the COSMOS tree for ESS scenario

context category	Context Level	Quality Parameters	Example
Social Activity Emergency	H	freshness accuracy	[14] [26]
Space/ Temporal	L, I, H	accuracy precision	[5] [11]
Identity Privacy	L, I, H	trust- worthiness	[13] [26] [19]

Table IV
QoC PARAMETERS' PRIORITY FOR DIFFERENT CONTEXT TYPES

level context. For instance, we consider that freshness and accuracy are important for social and activity context types because they rely on location which is very dynamic and demands recent and accurate values. On the other hand, trustworthiness is of particular importance for applications in the security and privacy domain.

IV. RELATED WORKS

After about a decade of research on context awareness, following the seminal work of A. Dey in 2000 [9], many works are concerned with context management, but few of them are especially interested in the quality of context information. The focus of this paper being to improve QoC management and use in different areas of pervasive computing, we review here the existing work on QoC management.

[8] and [21] present techniques to work with different probabilistic models at different context layers. For [8], in the first layer, the nearest to context sources, *Fuzzy logic* is adopted with filtering and buffering techniques. At the second layer, probabilistic techniques such as *Dempster-Shafer theory* are used to aggregate contexts from different sources. At upper layer, reasoning techniques like *Bayesian networks* are used. [21] presents a flexible context-aware architecture where a *stabilization mechanism* is added to the cycle : { collecting data \rightarrow decision making \rightarrow applying the decision using actuators } between each step. The stabilisation mechanism is composed by stabilized algorithms combined, at different layers (same as [8]), with probabilistic techniques and QoC.

[23] focuses on information fusion and work on issues in aggregation query with QoC specified by a precision range by using Dynamic Bayesian Networks and evolving data as a random-walk model. Selecting an action has a consequence

which can be measured by the cost of information acquisition, this cost being considered as the QoC parameter.

[24] presents a UML based structured model of context quality. Different quality issues are considered at each layer of context processing.

[17] uses quality of context to resolve conflicts in context-aware systems. It identifies different conflict types according to the context layer. During context acquisition, conflicts can occur in making selection among different sensors. The context processing layer may encounter conflicts in extracting high-level information. Context distribution has to deal with conflicts occurring during the context aggregation. At the applications level, different applications may have conflicting interests. The authors propose QoC based conflict resolving policies based on one QoC parameter for each suitable situation. However, this work does not consider policies combining several QoC parameters as could be done with our weighting model.

[10] focus is on an abstract processing model. The process calculates quality in different steps before using fusion algorithms to identify data with acceptable quality. The process checks for minimal trust, certainty and consistency. The Nexus system [20] presents a global context model and integrates many context models from different providers. They present a reference QoC model which covers and integrates the different aspects of QoC on all abstraction levels.

[12] concerns multi-sensor surveillance systems and uses quality of information (QoI) as a measurement of how valuable the information is to the user. This work considers four quality factors : accuracy, certainty, timeliness and integrity. A hierarchical model is proposed to compute the QoI of a surveillance system following two QoI computation approaches. The first one applies a function $f1$ on the measured factors with a chosen weight for each source I to obtain Q_i and then applies $f2$ on Q_i to obtain an overall Q . The Second computes a general quality for each factor to obtain an overall Q . Unlike our proposition, this work does not define guidelines to set the weight associated to each QoI factor.

V. CONCLUSIONS AND PERSPECTIVES

We define in this paper a fine-grain approach for evaluating the quality of context. Our approach details how to attribute weights to the different QoC parameters. The proposed model can directly benefit to the developers of context-aware applications as it transforms expert knowledge about context information into importance rating of QoC parameters. We provide a proof-of-concept prototype implementation of an application example with the COSMOS framework and the Siafu simulator to finely master the QoC attributes of several context attributes. We show that having a weighting QoC policy fosters a new view on context information and on how to use it. This view represents

the vision of a domain expert in addition to the traditional technical view.

For our next steps, we plan to use QoC to specify observation contracts between applications and the context reasoning system. A QoC contract definition would allow to perform more sophisticated reasoning in the fusion of low level context and in the extraction of high level context information.

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